Development of old-growth characteristics in uneven-aged forests of the Italian Alps

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Abstract

During the last millennia, all forests of the Italian Alps have been heavily affected by human land-use. Consequently, forest structures have been modified, and there are no old growth remains. In the last decades, however, many forests have been withdrawn from regular management, because wood production was unprofitable, and left to develop naturally. At the same time, in currently managed forests, silvicultural systems able to develop or maintain old-growth characteristics are being required. The aim of this paper was to assess the status and developmental dynamics of old-growth characteristics in mixed beech, silver fir, and Norway spruce montane forests of the eastern Italian Alps. We selected along a naturalness gradient (a) three old-growth forests in Bosnia and Montenegro (due to the lack of old-growth forests in the Italian Alps), (b) two forests withdrawn from regular management for at least 50 years, and (c) three currently managed forests. In each forest, we analysed 17 structural attributes, in order to assess their value as indicators of old-growth condition. Old-growth forests were characterized by significantly higher amounts of live and dead biomass, share of beech in the dominant and regeneration layers, and number of large trees. The diameter distribution was best described as a rotated sigmoid, differently from currently and formerly managed forest. We discuss the differences in old-growth characteristics across the management gradient and use our results to evaluate the effectiveness of retention prescriptions currently applied in the studied regions in maintaining or promoting old-growth structural attributes in managed forests.

Keywords

Forest structure
Coarse woody debris
Selection system
Rotated sigmoid
PCA
Retention forestry

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Introduction

Old-growth forests are "later stages in forest development that are often compositionally and always structurally distinct from earlier successional stages" (Franklin and Spies 1991). Old-growth forests host plant, fungi, and animals that are rare or absent in earlier developmental stages, and are important for regional biodiversity (Bauhus et al. 2009; Burrascano et al. 2013; Keeton 2006; Keeton and Franklin 2005). Moreover, they represent an important reference point for evaluating human impacts on forest ecosystems and for developing silvicultural systems able to emulate natural processes and fulfil socio-economic goals while maintaining a full range of ecosystem services (Wirth et al. 2009). As the definition implies, old-growth stages can occur also in managed forests that have developed for long periods without human influences and without stand-replacing natural disturbances. The time required for the development of old-growth characteristics in previously managed forests may vary from a few decades to a few centuries, depending on site features (e.g. disturbance regime and history, productivity), and tree species functional traits (e.g. growth rate, longevity, wood decay rate, etc.; Humphrey 2005; Motta et al. 2010).

Starting from the nineteenth century, silvicultural treatments in central and southern Europe were focused mainly on timber production. "Industrial" production forestry was based mainly on pure, even-aged stands subjected to short rotation periods, i.e. 10–40 % of the potential lifespan of the main tree species (Bauhus et al. 2009). Only a small part of the forests was subjected to systems based on mixed uneven-aged stands but, also in these systems, wood production was the main purpose. As a consequence, structural attributes typical of later developmental stages are strongly under-represented and, if present, restricted to small and remote forest reserves (Barbati et al. 2012; Peterken 1996).

In the last decades, a gradual reversal of this trend has been observed, with a decrease in timber removal, and many forests have been withdrawn from management (Castagneri et al. 2010; Motta et al. 2010; Vandekerkhove et al. 2009). At the same time, the scientific community has been advocating for forest management strategies that aim at the restoration of old-growth attributes that would benefit a wealth of taxa that are lacking or threatened in managed forests, even where close-to-nature forestry is applied (Lindenmayer and Franklin 2002; Lindenmayer et al. 2006). Policy frameworks have been set up to facilitate the attainment of this goal (e.g. the Helsinki process) and have in some case led to measurable results (Ammer 1991; Kohler 2010; Vandekerkhove et al. 2011).

Despite being an apparent oxymoron, the development of "old-growthness", i.e. the degree to which structural and functional attributes are similar to those associated to old-growth forests (Bauhus et al. 2009) can be facilitated by appropriate forest management measures. These can be described as either ecological restoration practices (Stanturf and Madsen 2002), e.g. extending thinning rotation periods, regulating stem density and regeneration to match wildlife habitat requirements, and mimic the effects of natural disturbances (Bergeron et al. 2007; Silver et al. 2013) or retention forestry (Beese et al. 2003; Gustafsson et al. 2010).

Gustafsson et al. (2012) defined retention forestry as "an approach to forest management based on the long-term retention of structures and organisms, such as live and dead trees and small areas of intact forests, at the time of harvest". Retention forestry aims at improving elements of old-growthness pertaining to stand structure, i.e. the quantity and quality of coarse woody debris (CWD), large old trees, and the amount of structural diversity. These elements are not exhaustive of old-growth characters, but provide surrogates for other ecosystem attributes, such as plant or animal diversity (Halpern and Spies 1995; Heilmann-Clausen and Christensen 2003; Kirby and Drake 1993; Lähde et al. 1999; Ódor et al. 2006; Siitonen 2001) with the advantage of being directly manipulated during forest management.

The aim of this paper was to identify the structural attributes that contribute to better differentiate between old-growth forests, actively managed forests, and forests withdrawn from regular management (FWRM) in mixed beech (*Fagus sylvatica* L.), silver fir (*Abies alba* Mill.), and Norway spruce (*Picea abies* (L.) Karst.) stands of the Alps and Dinaric mountain ranges. In light of our results, we discuss the effectiveness of current retention forestry aimed at promoting old-growthness in managed stands of the Italian Alps.

Materials and methods

Study sites

We focused our research on mixed, uneven-aged mountain forests belonging to the association *Piceo-Abieti-Fagetum*. These forests exhibit continuous canopy cover and multilayered vertical structure. In the European temperate forests, old-growth remnants are still present in remote protected areas of Eastern (Parviainen 2005) and South-eastern Europe (Korpel 1995; Nagel et al. 2012). They are highly significant for European silviculture, not only because of their natural value, but also because their structure served as a model to develop the silvicultural selection system (Korpel 1995; Leibundgut 1982; Susmel 1980).

This study was carried out in eight mixed montane forests of the Italian Alps and of the Dinaric mountains, co-dominated by silver fir, beech, and Norway spruce (Fig. 1; Table 1). We selected three actively managed forests and two FWRM in the eastern Italian Alps. Ordinary silvicultural management is carried out by harvesting single tree to small group maintaining a multilayered and unevenaged stand, and has a limited impact on the landscape. Selection cuttings are repeated every 8–10 years, and the main goal of the management is the conservation of the desired diameter distribution and species composition. Santo Stefano di Cadore has been managed by single tree selection since the age of the Republic of Venice (Volin and Buongiorno 1996). In Croviana and Amblar, application of single tree selection is more recent (Wolynski 1998). The two FWRM Val Navarza and Ludrin have developed without direct human influence since 1953 and 1962, respectively (Castagneri et al. 2010). Before the abandonment, these forests were managed using a silvicultural selection system, but due to their remoteness the cuts were probably less frequent but more intense than in stands closer to a road system. Due to the absence of old-growth forests in the Italian Alps (Motta 2002), we selected three old-growth forests in Bosnia-Herzegovina and Montenegro (Motta et al. in press, 2011; Nagel and Svoboda 2008) about 400 km south-east of the Italian border. Forest cover type, site conditions, and altitudinal range of old-growth forests are similar to the remaining five.

Fig. 1

Map of the study area. Location of sites (*AMB* Amblar, *CRO* Croviana, *CAD* Santo Stefano di Cadore, *LUD* Ludrin, *NAV* Navarza, *LOM* Lom, *BIO* Biogradska gora, *PER* Perućica) and management category (*triangles*: old growth; *circles*: FWRM; *squares*: managed)

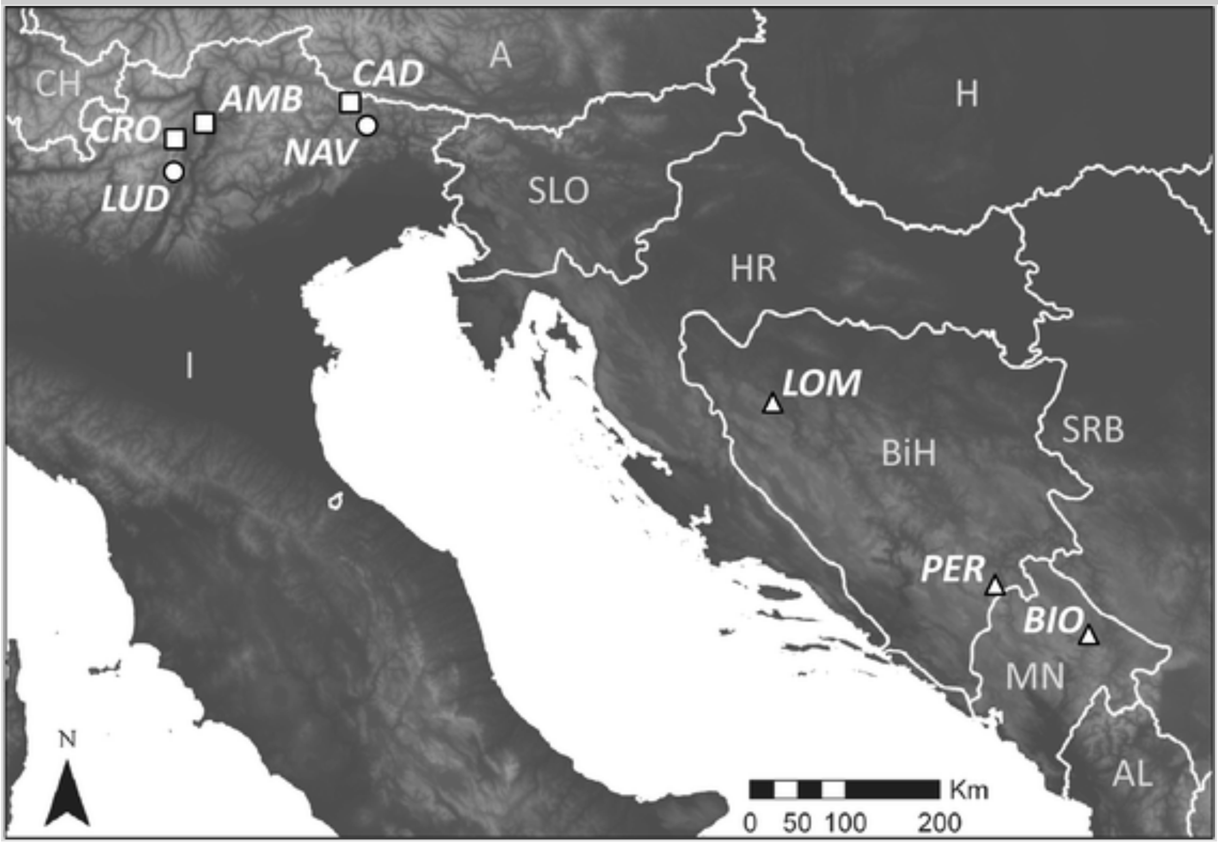


Table 1

Characteristics of the eight study sites

Site	Code	Location	Area (ha)	No. of plots	Altitude (m a.s.l.)	Slope (°)	Management category
Amblar	AMB	Italy, TN	5	13	1,150–1,220	5–25	Managed (single tree selection)

Croviana	CRO	Italy, TN	9	14	1,220–1,290	0–20	Managed (single tree selection)
Santo Stefano Cadore	CAD	Italy, BL	15	21	1,080–1,190	0–29	Managed (single tree selection)
Ludrin	LUD	Italy, TN	27	22	1,250–1,350	0–30	Withdrawn from regular management since 1962
Val Navarza	NAV	Italy, UD	37	33	1,300–1,570	12–34	Withdrawn from regular management since 1953
Lom	LOM	Bosnia-Herzegovina	40	40	1,250–1,520	0–40	Old-growth forest
Perućica	PER	Bosnia-Herzegovina	32	32	1,340–1,510	4–40	Old-growth forest
Biogradska gora	BIO	Montenegro	30	30	1,210–1,450	0–35	Old-growth forest

Field sampling

In each forest, located within a narrow elevation range (1,080–1,570 m a.s.l.), we selected a sector of 5–40 ha (Table 1), chosen with the help of local foresters in compliance to the following criteria: (a) mixed species composition, i.e. no species with >70 % contribution to total basal area; (b) for old-growth forests, core area or sector of core area in the optimum stage (Korpel 1995); (c) for managed forests, management unit(s) in the vicinity of the forest road system; and (d) for FWRM, unmanaged for the longest possible period according to available management plans.

In each forest, we surveyed the structure by a regular quadrat grid. Grid size varied from 70 to 120 m based on the size of the stand, resulting in one sampling point every 0.4–1.2 ha of forest. At each sampling point, three types of measurements were carried out (Motta et al. 2011): (1) species, diameter at breast height (dbh) to the nearest 0.01 m, and height (h) to the nearest 0.5 m of all living trees (dbh ≥ 7.5 cm) within a 615.5 m^2 circular plot (radius = 14 m); (2) species of each regeneration tree (h > 10 cm and dbh < 7.5 cm, i.e. seedlings and saplings) within a concentric, 113.1 m^2 circular plot (radius = 6 m); (3) the diameter of each log crossing a 50 m line (Motta et al. 2006) oriented northward from the centre of each sampling point (orientation bias was assumed to be negligible); and (4) base and top diameter of stumps (height < 130 cm), and dbh of snags (height > 130 cm) in a 50 × 8 m rectangular plot centred on the previous line.

In each site, we have measured the height of the overtopping trees in order to estimate the maximum height (the average of the 5 highest tree ha^{-1}) sensu Susmel (1980).

Statistical analyses

Volume of living trees, dead standing trees, and snags was calculated using local yield tables. Volume of logs was calculated according to line intercept sampling method, and the volume of stumps was estimated as a frustum of a cone using diameter at the top and diameter at the ground level (Motta et al. 2006).

In each plot, we computed 17 structural attributes for living trees and CWD (Table 2). We statistically compared structural attributes between management categories (managed, FWRM, old growth) by means of a nonparametric Kruskal–Wallis test, followed by Dunn's post hoc multiple comparison. In order to identify key gradients of structural variation under different management categories, we carried out a principal component analysis (PCA) on stand structural attributes. Highly correlated attributes (Pearson's $R > 0.75$) were excluded from further analysis (Table 2). The statistical significance of PCA axes was tested by random average under permutation, i.e. the average eigenvalue obtained under a randomization of the data matrix acquired from a randomization test based on eigenvalues. The randomization test was carried out as follows: (1) randomize the values within variables in the data matrix; (2) conduct a PCA on the reshuffled data matrix; and (3) repeat steps 1 and 2 a total of 10,000 times. The p value for each axis and each test statistic was then estimated as: (number of random values equal to or larger than the observed +1)/1,000. If the observed exceeds the average random value, that particular axis is considered to be nontrivial (Peres-Neto et al. 2005). PCA was performed using the function PRCOMP of the R statistical package, version 3.0 (R Core Team 2013).

Table 2

Forest structural characteristics of the eight study sites

Structural variables	Definition	Units	Used in	Managed forests (single tree selec

			PCA	AMB	CRO	CA
BA	Basal area	$m^2\ ha^{-1}$	x	44.5 ± 3.43	40.5 ± 3.63	40.6
D50	Trees with dbh > 50 cm	$n\ ha^{-1}$		80 ± 12.3	74 ± 9.0	48 ±
D80	Trees with dbh > 80 cm	$n\ ha^{-1}$	x	3 ± 2.2	10 ± 3.7	0 ±
HD	Shannon diversity diameter classes	cm	x	1.9 ± 0.05	1.9 ± 0.05	1.9 ±
QMD	Quadratic mean diameter	cm	x	32.9 ± 1.66	41.2 ± 2.92	25.7
REGEN	Regeneration density	$n\ ha^{-1}$	x	3,612 ± 1,373	1,009 ± 213	6,48
SDD	Standard deviation of the diameter	cm		18 ± 0.7	18.4 ± 1.61	14 ±
TPH	Tree density	$n\ ha^{-1}$		544 ± 45.4	354 ± 52.4	822
VOL	Volume of living trees	$m^3\ ha^{-1}$		622 ± 52.6	528 ± 55.0	453
CWD	Volume of coarse woody debris	$m^3\ ha^{-1}$		32 ± 6.5	48 ± 7.5	22 ±
SNAG50	Snags with dbh > 50 cm	$n\ ha^{-1}$		0 ± 0	1 ± 1.0	0 ±
STUMP	Stumps	$n\ ha^{-1}$	x	295 ± 20.5	201 ± 17.1	329
VLOG50	Volume of logs with diameter > 50 cm	$m^3\ ha^{-1}$	x	0 ± 0	0 ± 0	0 ±
VSNAG50	Volume of snags with dbh > 50 cm	$m^3\ ha^{-1}$	x	0 ± 0.0	6 ± 6.0	0 ±
VSTUMP	Volume of stumps	$m^3\ ha^{-1}$	x	15 ± 1.5	22 ± 1.9	20 ±
PERCFASY	Per cent basal area by beech	%	x	7.3 ± 1.5	0.7 ± 1.7	0.5 ±
REGFASY	Per cent regeneration by beech	%	x	22 ± 6.8	0.2 ± 1.2	1.8 ±
Number of				13	14	21

plots						

In order to classify and compare dbh distributions, we computed a pooled frequency distribution of tree diameters (midpoints of 5 cm dbh classes) by forest management categories (MAN, FWRM, and OG), using data from all living trees and plots (Goodburn and Lorimer 1999).

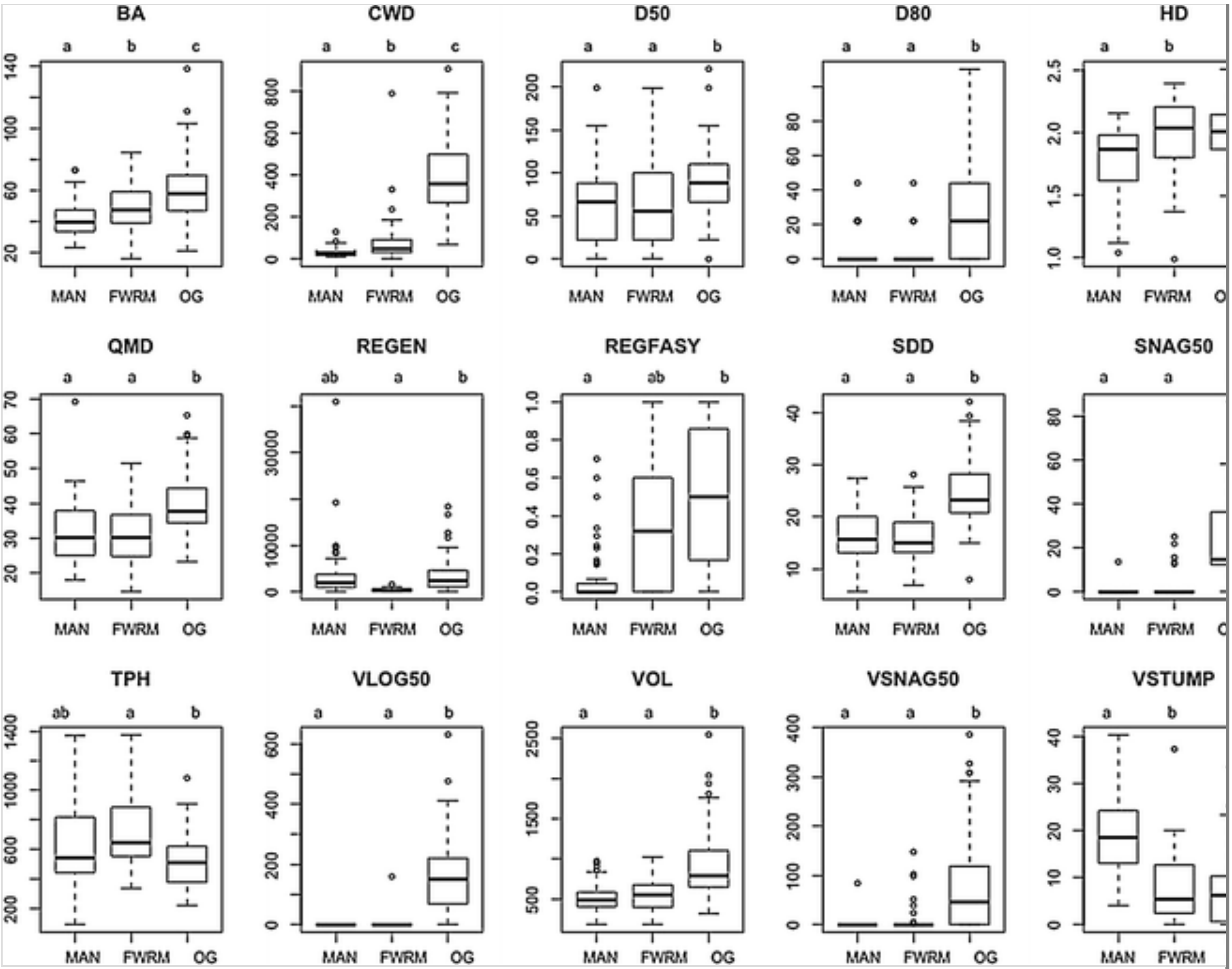
Following $\log_{10}$ transformation, we fitted each frequency distribution by concurrent models based on linear combinations of dbh, dbh^2, and dbh^3, in order to define its shape (Janowiak et al. 2008; Leak 1996). Because the logarithm of zero is undefined, we added 1.0 to the frequency of all dbh classes before log transformation. Among significant models, we selected the model with the highest adjusted R^2 and lowest root mean square error (RMSE) as the best fitting one. The shape of each diameter distribution was determined by examining the significance and sign of model parameters (Alessandrini et al. 2011; Janowiak et al. 2008).

Results

Old growth exhibited significantly higher quadratic mean diameter (QMD), volume of living trees (VOL) (763–1,031 m^3 ha^{-1} on average) and volume of CWD (327–420 m^3 ha^{-1}), density of trees with dbh > 50 and dbh > 80 (D50 and D80), volume of snags with dbh > 50 cm (VSNAG50), and volume of logs with diameter >50 cm (VLOG50) (Table 2; Fig. 2). FWRM had the highest tree densities (TPH) and lowest standard deviation of tree diameters (SDD), together with managed forests. The latter had the highest frequency of stumps (STUMP), and lowest basal area (BA), CWD, per cent basal area by beech (PERCFASY), per cent regeneration by beech (REGFASY), and Shannon diversity index for dbh (HD).

Fig. 2

Boxplots of 17 structural attributes in currently managed (MAN) forests, forests withdrawn from regular management (FWRM), and old growth (OG). Groups with *identical letters* are not significantly different from each other ($p < 0.05$)



PCA of uncorrelated attributes evidenced two significant principal components ($p < 0.001$, Monte Carlo test) that accounted for a cumulative 51.9 % of total variation (Table 3; Fig. 3). The type of management gradient was aligned along a direction from managed to old-growth forests of increasing deadwood (VSAG50, VLOG50), increasing incidence of beech (PERCFASY, REGENFASY), density of large tree (D80), and decreasing anthropogenic disturbance (STUMP, VSTUMP), and was relatively orthogonal to HD, QMD, and BA.

Table 3

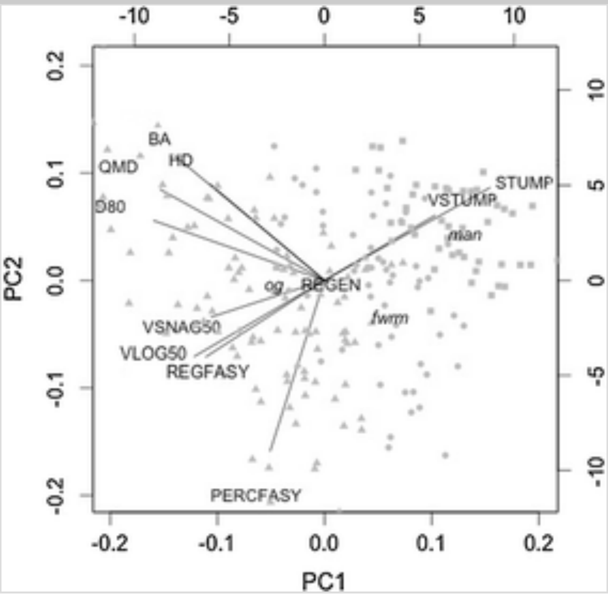
Principal component loadings for the first two principal components for the eight study areas

Statistical parameters	PC1	PC2
% of variance	34.32	17.57
Cumulative % of variance	34.32	51.89
p	0.001	0.001

BA	−0.36	0.41
D80	−0.40	0.20
HD	−0.27	0.32
QMD	−0.39	0.30
REGEN	−0.01	−0.01
STUMP	0.39	0.31
VLOG50	−0.31	−0.25
VSNAG50	−0.27	−0.12
VSTUMP	0.26	0.21
PERCFASY	−0.13	−0.56
REGFASY	−0.28	−0.25
Codes in Table 2		

Fig. 3

Principal component analysis (PCA of 207 plots) of structure surveyed in the study sites. *Arrows* represent selected forest structure descriptors (see Table 2 for codes). *Triangles*: old growth (OG); *circles*: withdrawn from regular management (FWRM); *squares*: managed forests (MAN)



The $\log_{10}$ diameter cumulative distribution of old-growth forests (Fig. 4) was best described as a rotated sigmoid ($p < 0.05$), while it exhibited a concave and a variable shape in managed forests and FWRM, respectively (Table 4).

Fig. 4

Diameter distributions in managed forests (MAN), forests withdrawn from regular management (FWRM), and old growth (OG)

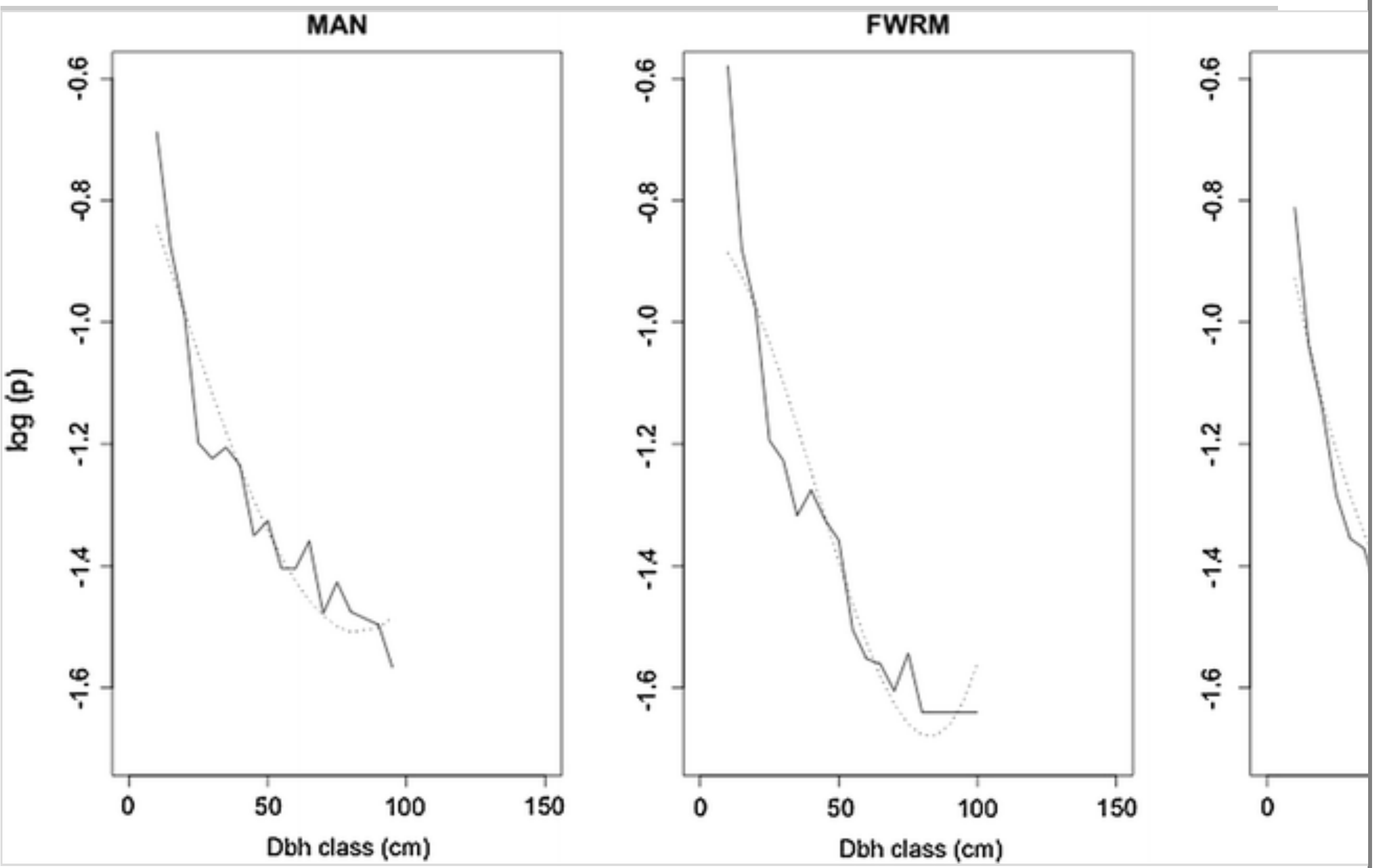


Table 4

Signs (+/−) of significant coefficients (dbh, dbh^2, and dbh^3) in polynomial regressi models used to determine diameter distribution shape (Janowiak et al. 2008) in uneve aged forests

Management category	SSE	AIC	RMSE	Adj. R^2	dbh	dbh^2	dbh^3	Distributio shape
AMB	15.901	224.432	0.195	0.933	ns	ns	+	Unclassifie
CAD	19.417	226.948	0.193	0.946	−	ns	ns	Negative Exp.
CRO	13.747	222.598	0.204	0.915	ns	+	+	Unclassifie
Managed	13.601	222.464	0.121	0.971	−	ns	+	Concave
LUD	19.791	227.188	0.214	0.935	ns	ns	+	Unclassifie
NAV	17.300	225.494	0.157	0.960	ns	+	+	Unclassifie

FWRM	14.692	223.436	0.132	0.967	ns	+	+	Variable
LOM	11.997	220.884	0.148	0.949	−	ns	ns	Negative Exp.
PER	8.889	217.107	0.127	0.949	−	+	−	Rotated Sig
BIO	8.054	215.865	0.168	0.902	−	ns	ns	Negative Exp.
Old growth	8.737	216.890	0.086	0.976	−	+	−	Rotated sigmoid

All the models grouped in the management categories were significant ($p < 0.001$), and their performance was compared through goodness of fit indices: adjusted R^2 (Adj. R^2), RMSE, Akaike information criterion (AIC), and sum of squares due to error (SSE)

The maximum height was between 37 and 45 m for managed forests, 40–41 m for FWRM and between 46 and 55 m in the old-growth forests.

Discussion

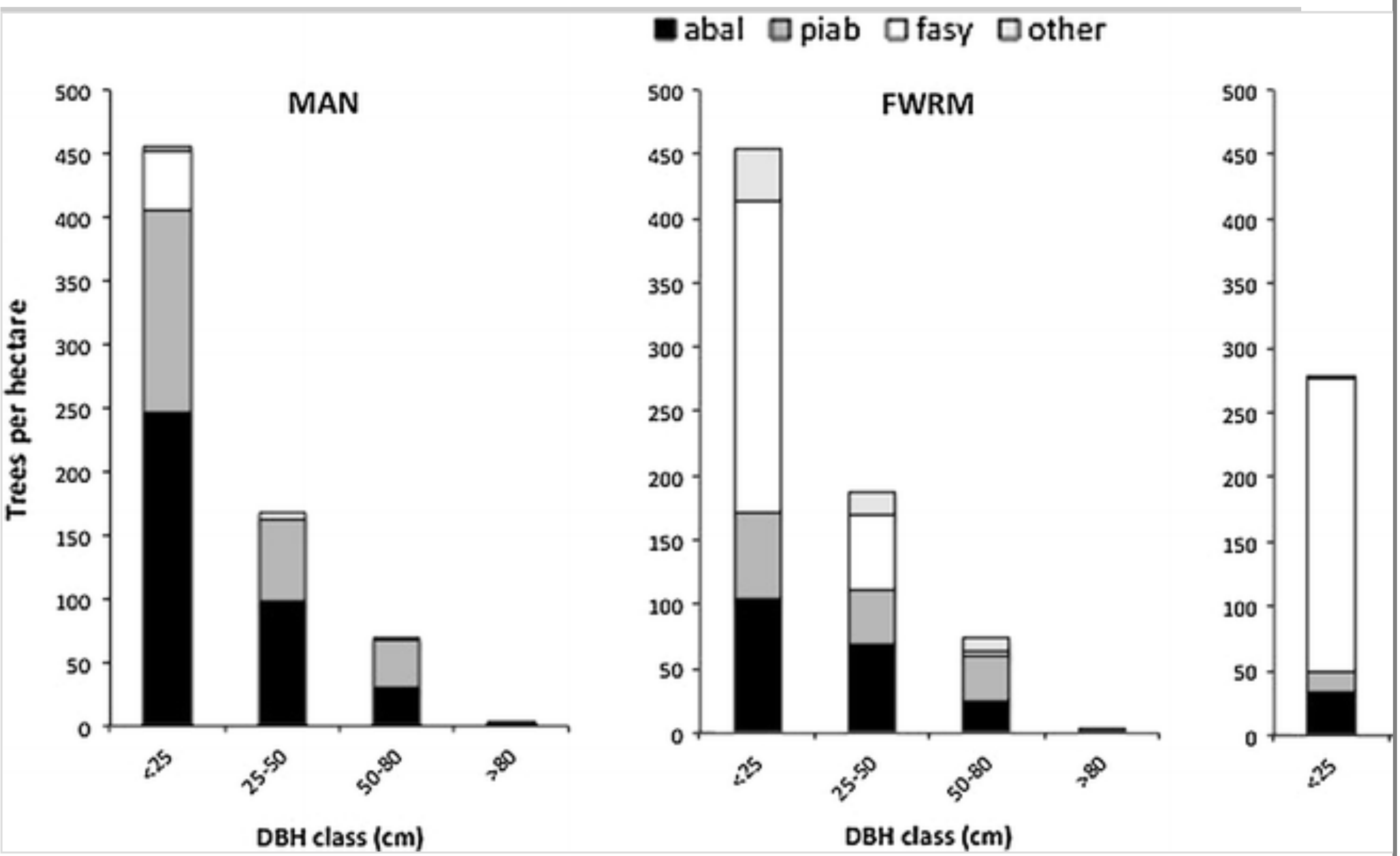
Forest structure

Structural attributes were effective in discriminating managed and old-growth mixed mountain forests of central-southern Europe, consistently with previous research (Boncina 2000; Franklin and Van Pelt 2004; Kuuluvainen et al. 1996; Siitonen et al. 2000). The most significant differences arose from the amount and quality of large woody debris (VSNAG50, VLOG50), and the frequency of very large trees (D80), i.e. variables directly influenced by management intensity.

Other indicators associated with the management gradient were maximum height and species composition. The difference in maximum height between managed/FWRM and old-growth forests, i.e. about 5 m, is probably due to the fact that management prevents the trees from a living their complete lifespan (Susmel 1980). Species composition, on the other hand, differed between FWRM/old growth and managed forests, especially due to a significantly lower presence of beech in the latter. Even if all stands belonged to the *Abieti-picenion* Br.-Bl. 1939 (group F5: mixed beech forests according to the map of potential natural vegetation in Europe; Bohn et al. 2003), past management in the Alps resulted in a negative selection on beech, due to a preference for spruce and fir that had a more valuable timber (Poldini and Bressan 2007). This is in contrast to the observed current trends observed in most old-growth forests of central-eastern Europe where there is long-term quantitative increment of beech and a quantitative and qualitative reduction of the conifers (Diaci et al. 2011; Keren et al. 2014). In forests left unmanaged for some decades, beech has started to increase its share in the lower diameter classes, even if large individuals are still lacking compared to old-growth forests (Fig. 5). A similar trend occurred in the regeneration layer (regeneration density, Table 2). Current silvicultural management protocols have abandoned negative selection on beech, but the low number of seed trees, as a legacy of past management, implies that these stands still experience a scarcity of beech in the intermediate and regeneration layers as well. It is possible, however, that the quantity and quality of CWD would differ between beech-rich (old growth) and beech-devoid forests (FWRM and managed), due to the highest production of large branches and fastest decay rate of the broadleaf species (Chirici et al. 2014) as opposed to the conifers.

Fig. 5

Relative frequency (average number of trees ha^{-1}) for increasing size classes in managed forests (MAN), forests withdrawn from regular management (FWRM), and old growth (OG)



Old-growth forests were represented as a distinct group on the ordination plot that expressed gradients of large tree density, biomass, specific composition, quantity of deadwood (logs and snags), and incidence of beech. The scattered distribution of old-growth sampling points on the ordination plot revealed a high heterogeneity of forest structure, as opposed to the smaller variability of structural attributes in formerly and currently managed forests.

On the other hand, there was a wide overlap of the structural data coming from managed forests and FWRM. This is mainly due to the relatively short period that FWRM has spent without direct human influence, about 50 and 60 years, respectively. Mature managed stands are expected to take about one century to reach amounts of deadwood and large living trees about half of those found in old growth (Christensen et al. 2005; Nilsson et al. 2002; Vandekerkhove et al. 2009). FWRM differed from managed forests mainly for increased tree density and CWD volume (Sitzia et al. 2012). The amount of CWD in FWRM was in line with what is expected in a forest that was left unmanaged for about 50 years (Meyer and Schmidt 2011; Motta et al. 2006; Vandekerkhove et al. 2009), and twice as much as in managed forests, even though CWD in the studied managed forests was already much higher than the Italian average for similar forests, i.e. 7 m^3 ha^{-1} for beech, 16 m^3 ha^{-1} for spruce, and 21 m^3 ha^{-1} for silver fir-dominated forests (INFC 2005). At the current developmental stage, mortality in FRWM was mainly concentrated in small and intermediate diameters, and only sporadically affected the dominant layer. Consequently, the total amount of CWD and the density of large snags and logs were still very low if compared with old-growth forests (for FWRM and old growth 70–85 vs 327–420 m^3 ha^{-1} of CWD and 1–2 vs 19–28 snags >50 cm dbh ha^{-1}). However, CWD in both managed and abandoned forests in this study are higher than 20–30 m^3 ha^{-1}, i.e. the proposed threshold to safeguard the complete spectrum of species that rely on deadwood (Angelstam et al. 2003; Müller and Bütler 2010). The density of very large trees (dbh > 80 cm) was higher in the managed forests than in FWRM (0–10 vs 0–3 ha^{-1}). This is due both to recent retention forestry policies in managed forests and to the fact that before the abandonment, due to their remoteness, the last cuts were probably in between from a selection and a high-grading system. In any case, the density of very large trees of both managed and FWRM was very low if compared with old-growth forests (18–37 ha^{-1}).

Another important difference between the three management categories was the shape of the diameter distributions (Fig. 4; Table 4). Traditionally, the diameter distribution of both managed and unmanaged uneven-aged forests has been represented as reverse J-shaped or negative exponential (de Liocourt 1898; O'Hara and Gersonde 2004). Recent research has revealed that, for primary forests, it can be better modelled by a rotated sigmoid (Alessandrini et al. 2011; Goff and West 1975; Janowiak et al. 2008). Our results confirmed the latter hypothesis, but not the former, as the log-transformed diameter distribution of managed forests was found to fit a concave function. The concave shape is the result of a deficit in intermediate size classes, with the addition of which would be classified as a rotated sigmoid. Emergence of a concave distribution in our managed forests may be explained by retention forestry prescriptions, albeit very recent, that aimed at the conservation of cavity-nesting birds by increasing the number of large diameter trees. Similar studies have pointed out that the concave distribution is evident at small spatial scales (<0.8 ha; Janowiak et al. 2008) as a result of small gap dynamics or, in our case, to single tree selection practices. Old-growth stands are characterized by an ongoing gap-phase dynamics (Bottero et al. 2011; Kucbel et al. 2010) that can explain the coexistence of multiple structural stages in the same forest (hence the large scatter of OG points on Fig. 3). Conversely, in forests currently or formerly managed for timber, natural disturbances have been replaced by anthropogenic intervention, which may have led to a much greater structural homogeneity (Attiwill 1994) and to a different shape of the diameter distribution. Besides the studied structural parameters, the tree spatial pattern, analysed in large permanent plots (Lingua et al. 2011), is another important indicator of old-growthness, differentiating more or less random structures resulting from active management, from a gradient of clumping and subsequent mortality-induced regularization from ongoing competition in natural gaps typical of unmanaged and old-growth forests (Moeur 1997).

Finally, the variable shape of FWRM diameter distribution may be a consequence of the structural re-organization that forests managed for a long period of time experience after the abandonment.

Retention forestry policies

Notwithstanding some concerns about costs, unwanted negative impacts, and social acceptability, foresters and stakeholders have recently increased their awareness about the importance of conserving biodiversity in regular forest management activities and it has been common practice to leave dead and living trees for biodiversity purposes (Gustafsson et al. 2012; Larrieu et al. 2012).

All the managed forests were, from a silvicultural point of view, overstocked. The increment maximization and long-term structural stability in mixed spruce-fir-beech forests should be attained at around 350–400 m^3 ha^{-1} (Schütz 1996), while the observed volumes (453–622 m^3 ha^{-1}) were much higher. The management regime in selection forests does not depend only on theoretical approaches, but it is strongly influenced by social and economical conditions.

Like most aspects of forest legislation in Italy, the strictness of retention rules in the alpine region varies on a regional/autonomous province basis, and whether or not forests are within a Natura 2000 protected area (Table 5). The rules are stricter in regions, such as Piedmont or Lombardy, where most traditional silvicultural systems are coppices based on a rotation of 20–30 years. The range of required retention is wider, but at the same time the rules are not so strict, in regions rich in high forests, where there is a long tradition of close-to-nature and sustainable forest management.

Table 5

Retention forestry in northern Italian regions and autonomous provinces according to current regional/provincial laws

Region/Province	Retention forestry measures All forests	Retention forestry measures Natura 2000 forests	Other	Notes
Piemonte	Some ageing trees (no definite number and no marking) adviced as a “good practice”	Living ageing trees (quantity not defined) and 2 dead trees ha^{-1} (snags or logs) if present. Additional retention measures scheduled locally for Natura 2000 forests		Conservation of dead or decaying habitat trees is advised in Natura 2000 forests
Valle d’Aosta Autonomous Region		Retention measures scheduled locally for Natura 2000 forests		Conservation of dead or decaying habitat trees is advised in Natura 2000 forests
Liguria		5 dead trees ha^{-1}, if present. Other additional measures scheduled locally for Natura 2000 forests		Conservation of “biodiversity islands”, old trees, biodiversity trees is advised in Natura 2000 forests
	2 living ageing trees ha^{-1}	Retention		

Lombardia	(marked, the trees must be replaced in case of death)	measures scheduled locally for Natura 2000 forests		Conservation of dead or decaying habitat trees is advised in Natura 2000 forests
Bolzano Autonomous Province	Some ageing trees (no definite number and no marking)	Retention measures scheduled locally for Natura 2000 forests		According to the provincial forest rules, some ageing trees should be retained for biodiversity purposes in all the forests. Conservation of dead or decaying habitat trees is advised in Natura 2000 forests
Trento Autonomous Province	Some ageing trees (no definite number and no marking)	Retention measures scheduled locally for Natura 2000 forests		According to the provincial forest rules habitat trees, old or monumental trees, rare species should be retained for biodiversity purposes in all the forests. Conservation of dead or decaying habitat trees is advised in Natura 2000 forests
Veneto		Retention measures scheduled locally for Natura 2000 forests	Public funding (up to 200 € ha^{-1}) for owners that agree to preserve large living trees and dead trees (marked)	Conservation of dead or decaying habitat trees is advised in Natura 2000 forests
Friuli Venezia Giulia Autonomous Region	Some ageing trees (no definite number and no	2 living trees (dbh > 50 cm if present) and 1 dead tree (dbh > 40 cm if present) ha^{-1}. Other additional measures		According to the regional forest rules, some ageing trees should be retained for biodiversity purposes. Conservation of dead or decaying habitat

	marking)	scheduled locally for Natura 2000 forests		trees is advised in Natura 2000 forests

However, the quantity and quality of retention of old-growth elements that would be adequate for conservation purposes are not known. On one hand, current prescriptions require the retention of minimal densities (0–5 ha^{-1}) of ageing or standing dead trees (Table 5). This figure is comparable to what is being prescribed in actively managed forests of western and central Europe (e.g. Flanders: 4 % of total stock; Baden-Wurttenberg: 15 trees every 3 ha; Spielmann et al. 2013; Vandekerkhove 2013), but far below the levels detected by this study in unmanaged and old-growth forest, and lower than what is recommended for the conservation of specific organisms such as woodpeckers (Bütler 2003).

Moreover, the prescriptions ignore key components of habitat and ecosystem functioning, such as structural diversity or deadwood on the ground, and it is not known what quantity and quality of retention of old-growth elements would be adequate for the set conservation purposes, i.e. the habitat requirements of plant and animal species to be protected at each site are often unclear (Paillet et al. 2010).

Finally, retention strategies at the tree or stand scale should be supported by prescriptions on a larger scale, such as restoration of less natural forest ecosystems and establishment of set-aside areas (forest reserves), aiming at restoring landscape connectivity, and building an effective biodiversity network (Bengtsson et al. 2000; Fahrig 2003; Lindenmayer and Franklin 2002).

Conclusions

Both managed and FWRM-mixed spruce-fir-beech forests of the Italian Alps have currently few old-growth structural elements. An increase of such elements is desirable in order to improve ecosystem functioning and biodiversity conservation.

Live biomass and large-sized living trees, CWD biomass in different decay stages, large snags, and basal area of beech were the most important variables discriminating the three management categories. This result is aligned to the current body of literature, but nonetheless contains valuable information for future studies on indicators of biodiversity.

The establishment of retention forestry measures is relatively recent, but despite their limited scope and strictness, some effects may be achieved relatively quickly, as we observed in forests where management was abandoned in the last decades, i.e. an increment of large trees and CWD, and a potential shift from negative exponential to concave diameter distribution. On the other hand, 50 years of withdrawal from management are obviously not enough to approximate the degree of old-growthness found in pristine reference forests. According to Nilsson et al. (2002), in boreal forests, 100 years without management may be enough to hide the traces of past cutting (even if the structure of the forests may be still influenced by the past human disturbances). This is not the case in the studied mixed forests of the Alps, where the development of old-growth structural characteristics is very slow, and where past management has probably introduced a temporal lag in this process. At the same time, our findings highlight additional stand attributes to be targeted by future retention forestry policies. While in the past the traditional selection management was oriented mainly towards maintaining the targeted structure and composition, our results evidenced that tree and CWD retention and the CWD decay processes are important for the restoration of the biological diversity. Monitoring and research need to be enhanced in order to modify existing silvicultural measures based on this evidence and assess their effect through time.

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Conflict of interest

None declared.

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